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DETERMINATION OF THE GRAVITATIONAL FIELD OF THE MOON BY THE MOVEMENT OF THE ARTIFICIAL MOON SATELLITE LUNA-10

by

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DETERMINATION OF THE GRAVITATIONAL FIELD OF THE MOON BY THE MOVEMENT OF THE ARTIFICIAL MOON SATELLITE LUNA-10

By: E. L. Akim

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09 English Title DETERMINATION OF THE GRAVITATIONAL FIELD OF THE MOON BY THE MOVEMENT OF THE ARTIFICIAL MOON SATELLITE LUNA-10

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ABSTRACT : To determine the noncentral gravitational field of the Moon, the motion of the artificial Moon satellite "Luna 10" is analyzed with gravitational forces of the Earth and the Sun taken into account. From the statistically processed measurements of the trajectory of Luna-10 carried out over the period of its existence (from April 3 to May 30, 1966), it is established that the effect of noncentrality of the gravitational field of the Moon is an essential factor in the evolution of the orbit of Luna-10. The perturbations of its circumlunar orbit due to noncentrality of the gravitational field of the Moon are particularly noticeable in the evolution of the longitude of the ascending node Ω and the angular distance of the pericenter to the ascending node ω. The perturbations of elements Ω and ω of Luna-10 during the time of its existence (460 revolutions) due to noncentrality of the gravitational field of the Moon and due to gravitational effects of the Earth and the Sun (the gravitational effects of other planets are neglected) are presented as functions of the number of revolutions of the Moon satellite. A comparison of the results shows that perturbations for Luna-10 due to noncentrality of the gravitational field of the Moon exceed the perturbations due to gravitational forces of the Earth and the Sun 5 to 6 times. The gravitational potential of the Moon is taken in the form of expansion in spherical functions with unknown coefficients (the gravitational field parameters) C_{nm} and d_{nm} ($n = 2, 3, \ldots, m = 0, 1, \ldots n$).
As a result of processed measurement data, the numerical values for eleven expansion coefficients are derived which are presented with maximum possible errors. To illustrate the determined gravitational potential of the Moon, the level surface passing through the point with spherical coordinates $r = 1738$ km, $\psi = 0$, $\lambda = 0$ is analyzed. The level lines obtained by intersecting this surface by the equatorial plane of the Moon, the zero meridian plane ($\lambda = 0$), and the plane corresponding the meridian $\lambda = 90^\circ$ are presented. Orig. art. has: 4 figures. English translation: 7 pages.

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration
А а	*А а*	A, a
Б б	*Б б*	B, b
В в	*В в*	V, v
Г г	*Г г*	G, g
Д д	*Д д*	D, d
Е е	*Е е*	Ye, ye; E, e*
Ж ж	*Ж ж*	Zh, zh
З з	*З з*	Z, z
И и	*И и*	I, i
Й й	*Й й*	Y, y
К к	*К к*	K, k
Л л	*Л л*	L, l
М м	*М м*	M, m
Н н	*Н н*	N, n
О о	*О о*	O, o
П п	*П п*	P, p
Р р	*Р р*	R, r
С с	*С с*	S, s
Т т	*Т т*	T, t
У у	*У у*	U, u
Ф ф	*Ф ф*	F, f
Х х	*Х х*	Kh, kh
Ц ц	*Ц ц*	Ts, ts
Ч ч	*Ч ч*	Ch, ch
Ш ш	*Ш ш*	Sh, sh
Щ щ	*Щ щ*	Shch, shch
Ъ ъ	*Ъ ъ*	"
Ы ы	*Ы ы*	Y, y
Ь ь	*Ь ь*	'
Э э	*Э э*	E, e
Ю ю	*Ю ю*	Yu, yu
Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH

DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}
rot	curl
lg	log

DETERMINATION OF THE GRAVITATIONAL FIELD OF THE MOON BY THE MOVEMENT OF THE ARTIFICIAL MOON SATELLITE LUNA-10

E. L. Akim

An examination is made of the movement of the artificial satellite of the moon, Luna-10, in the central field of gravitation of the moon with the taking into account of the gravitational effect of the earth, the sun, and the planets.

If the gravitational field of the moon were central and the effect of external bodies did not exist the motion of the satellite would be along an undisturbed orbit (the Kepler ellipse), the form and dimensions of which would remain unchanged in absolute space. The noncentral quality of the gravitational field of the moon and the action of the outer bodies, the principal ones of which are the earth and the sun bring about disturbances in the motion of the satellite. Under the action of the disturbances of the orbit, the satellite in the course of time evolutionizes.

The disturbing influence of the earth and the sun on the movement of the satellite of the moon is well known. The greatest interest is afforded by the evolution of the orbit of the satellite in respect of the unknown noncentral quality of the field of gravitation of the moon. Knowledge of this evolution enables one to determine the

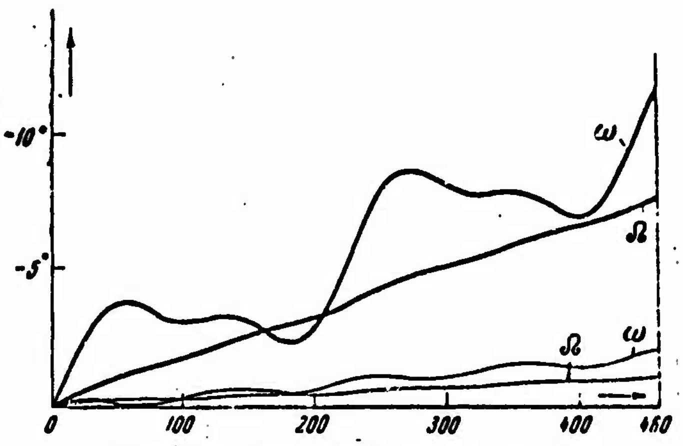
parameters of the gravitational field of the moon.

For revealing the evolution of the orbit of the artificial satellite, Luna-10, recourse was had to measurements of the trajectory of the movement of the satellite occurring during the course of the whole time of its active existence (3rd of April to the 30th of May, 1966). The trajectory measurements were submitted to statistical processing for the purpose of joint determination of the parameters of the gravitational field of the moon and the elements of the orbit of the satellite. At the basis of the procedure of the processing of the measurements there has been put the analytical theory of the movement of the satellite of the moon, which made it possible to embrace by a single computation the whole two-month measuring interval of the motion of the satellite.

The description of the selenocentric motion of the satellite and the motion of the moon around its own center of mass was worked out in the Cartesian rectangular selenocentric system of coordinates XYZ. The plane XY of this system corresponds with the plane of the average equator of the moon, and the plane XZ with the plane of its zero meridian of the period t_0. The directions of the axes of the system are motionless with respect to the stars. The axis X of the system is directed to the earth, the axis Z to the North Pole of the moon, and the axis Y completes the system to the right. For the description of the motion of the satellite there are used the elements of its orbit: the great semiaxis a, the eccentricity e, the inclination i, the longitude of the rising node Ω, the angular distance of the pericenter from the node ω, and the time of the passing of the node T_Ω. (The reading off of the angular orbital elements i, Ω, ω is done from the plane of the average equator of the moon and its zero meridian of the period t_0 by the method accepted in celestial mechanics). It

is presumed that the turning of the moon around its own center of mass occurs in accordance with Cassini's laws — uniformly around a motionless axis OZ of the introduced system of coordinates. The motion of the center of the mass of the moon (beginning of the system of coordinates) in the geoequatorial system of coordinates with average equinox of the period of 1960 (0) is given by Brown's theory.

The noncentral quality of the gravitational field of the moon is an essential fact determining the evolution of the satellite Luna-10. The disturbances of the orbit of the satellite which arise because of the noncentral quality of the field of gravitation of moon are revealed with special clarity in the evolution of the longitude Ω of the rising node of the satellite and the angular distance ω of the pericenter from the node. This evolution of the elements Ω and ω of the orbit of the satellite during the time of its active existance is shown in Fig. 1 as a function of the number of turns of the satellite. The evolution of the parameters Ω and ω contains an obvious secular drift leading to a regression of both parameters. Onto the secular drift of the parameter ω there is superimposed a noticeable periodical disturbance. For 460 turns of the satellite the disturbances of the parameters Ω and ω, brought about by the noncentral quality of the field of gravitation of the moon reach the values $\Delta\Omega = -7.7^\circ$



number of revolutions of satellite

Fig. 1. Disturbances in longitude Ω of the rising node (unit) and angular distance of the pericenter from the node of the orbit. The heavy lines mean on account of the noncentral quality of the field of gravitation of the moon and the thin lines mean on account of the gravitational influence of the earth and the sun.

and $\Delta\omega = -11.8^{\circ}$. The disturbances of the inclination i of the orbit of the satellite and its eccentricity e have basically a periodical character and have an amplitude of $\Delta i \approx 0.15^{\circ}$ and $\Delta e \approx 0.003$.

The disturbances of the orbit of the satellite on account of the noncentral quality of the field of gravitation of the moon lead to disturbances of its coordinates, amounting for one turn of the satellite to the value $|\Delta \bar{r}| \approx 0.75$ km.

The gravitational influence of the earth and the sun on the motion of Luna-10 also leads to the evolution of its orbit. This influence brings about a regression of the node and pericenter of the orbit of the satellite, which are also shown in Fig. 1. During the time of the active existence of the satellite these disturbances amount to the value $\Delta\Omega = -1^{\circ}$ and $\Delta\omega = -2^{\circ}$. Under the influence of the earth and the sun the eccentricity of the orbit of the satellite becomes less in the interval of time under consideration. In an almost unchangeable great semiaxis of the orbit the lessening of the eccentricity leads to an increase in the pericenter of the orbit. The disturbances of the coordinates of the satellite Luna-10 brought about by the action of the earth and the sun for one turn of the satellite do not exceed the value $|\Delta \bar{r}| \approx 0.11$ km.

The comparative evaluations presented show that for the orbit of the Luna-10 the disturbances brought about by the noncentral quality of the field of gravitation of the moon by a factor of 5 or 6 exceed the disturbances brought about by the gravitational effect of the earth and the sun. The planet disturbances of the motion of the satellite in the interval of time under consideration are small and are therefore not taken into the reckoning.

The processing of the trajectory measurements containing their single dynamic bond on the interval of flight of the satellite Luna-10

in two lunar months made it possible to determine the quantitative characteristics of the noncentral quality of the gravitational field of the moon.

The expression for the gravitational potential U of the moon is taken in the form of an expansion into series in accordance with the spherical functions

$$U(r, \psi, \lambda) = \frac{\mu}{r}\left\{1 + \sum_{n=2}^{\infty} \sum_{m=0}^{n} \left(\frac{R}{r}\right)^n \times \right.$$
$$\left. [c_{nm} \cos m\lambda + d_{nm} \sin m\lambda] P_n^m(\sin \psi)\right\},$$

where μ is the mass of the moon, R is its average radius; r, ψ, and λ are the spherical coordinates of the points: r is the polar radius, ψ is the latitude read from the average equator of the moon, λ is the longitude read from the zero meridian of the period t_0, and $P_n^m(\sin \psi)$ are the attached Legendre functions. As the parameters to be determined of the gravitational field of the moon there are used the coefficients c_{nm} and d_{nm} of this analysis.

As the result of the processing of the trajectory measurements, there are obtained numerical values for eleven coefficients of the analysis of the gravitational potential of the moon. These values together with their maximum possible errors are given below.

$$c_{20} = (-0.206 \pm 0.022) \cdot 10^{-3},$$
$$c_{21} = (0.157 \pm 0.059) \cdot 10^{-4},$$
$$d_{21} = (0.361 \pm 0.358) \cdot 10^{-5},$$
$$c_{22} = (0.140 \pm 0.012) \cdot 10^{-4},$$
$$d_{22} = (-0.139 \pm 0.145) \cdot 10^{-5},$$
$$c_{30} = (-0.363 \pm 0.099) \cdot 10^{-4},$$
$$c_{31} = (-0.568 \pm 0.026) \cdot 10^{-4},$$
$$d_{31} = (-0.178 \pm 0.032) \cdot 10^{-4},$$

$$c_{32} = (0.118 \pm 0.047) \cdot 10^{-4},$$
$$d_{32} = (-0.702 \pm 4.595) \cdot 10^{-6},$$
$$c_{40} = (0.333 \pm 0.270) \cdot 10^{-4}.$$

Between the errors in the determination of the parameters C_{20} and C_{40} there is a substantial correlation. The coefficient of the correlation $k = 0.99$. The mutual correlation between the errors of the remaining parameters to be determined does not go above the figure 0.4.

The numerical values presented for the parameters C_{20} and C_{22} agree with the values known for them obtained in accordance with the libration measurements (1).

The difference from zero of the coefficients c_{nm} with the odd suffix m and the coefficients d_{nm} with the even suffix m is evidence that the gravitational fields on the side of the moon visible from the earth and on that invisible from the earth are not symmetrical.

For illustration of the determined gravitational potential of the moon, there is considered the surface of a plane running through a point with the

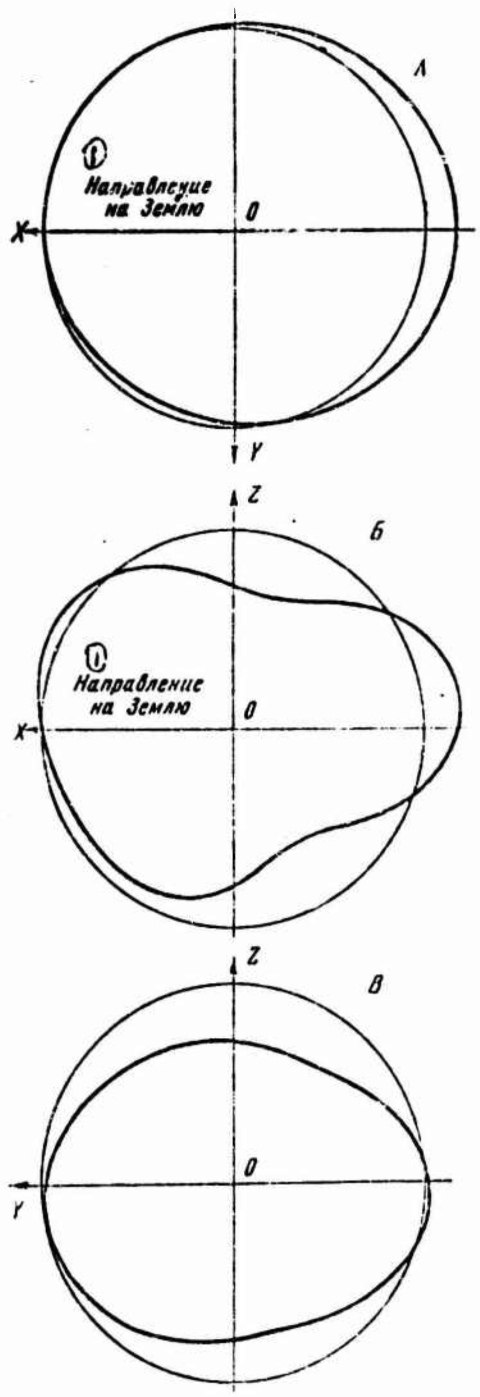


Fig. 2. Sections of the surface of the level of gravitational potential of the moon (radial inclination from the circumference increased by 1,000 times). A is the equatorial, Б the meridional ($\lambda = 0$), and B is the meridional ($\lambda = 90°$). KEY: 1) In the direction of the earth.

spherical coordinates r = 1738 km, ψ = 0, λ = 0. In the Fig. 2 there are constructed lines of the plane or level obtained by intersections of this surface by the equatorial plane XY (Fig. 2 A), the plane of the zero meridian XZ (Fig. 2 Б), and the meridional plane YZ corresponding to the longitude $\lambda = 90^{\circ}$ (Fig. 2 B). The radius of the circumference in these drawings corresponds to the average radius of the moon, equal to 1738 km. The radial deviation of the lines of the level from the circumference for clarity is drawn with an exaggeration of a thousand times.

There is seen the pear-shaped quality of the surface of the potential with the bulging on the reverse side of the moon. The pear-shaped effect is formed basically under the influence of terms in the analysis of the potential which contain the tesseral harmonic P_3^1 (with the coefficient c_{31}) and the zonal harmonic P_2^0.

The results presented above are only preliminary. Further processing of the trajectory measurements in accordance with Luna-10 and analysis of the movement of succeeding satellites of the moon will make it possible to refine and supplement the parameters obtained for the gravitational potential of the moon and also to refine the movement of its center of mass.

Entered
September 13, 1966

Literature Cited

1. Goudas, C. L. Icarus, No. 3, p. 375 (1964).